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**Civilian Radioactive Waste Management System  
Management & Operating Contractor**

**Unsaturated Zone Flow and Transport Model Process Model Report**

**TDR-NBS-HS-000002 REV00**

**March 2000**

Prepared for:

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## EXECUTIVE SUMMARY

The Unsaturated Zone (UZ) Process Model Report (PMR) describes the modeling, analysis and current understanding of fluid flow and chemical (solute and colloidal) transport through the UZ at Yucca Mountain. The UZ PMR is supported by 24 Analysis/Model Reports (AMRs) which provide detailed descriptions of the various UZ models and analyses. The primary purpose of the UZ PMR is to develop models for Total System Performance Assessment (TSPA) that evaluate the post-closure performance of the UZ. The models in the UZ PMR consider two principal factors (factors identified by the Yucca Mountain Project that greatly affect the performance of the potential repository), which are seepage into drifts and radionuclide retardation in the UZ. Seven other factors (factors of secondary importance) that relate to climate/infiltration, percolation flux and coupled processes are also considered.

The UZ PMR models are built upon the Integrated Site Model (ISM) and conceptual models for flow and transport through the UZ that have been developed from site-specific data, together with scientific and technical knowledge associated with flow and transport at analog sites and other UZ studies. The construction of mountain- and drift-scale numerical grids for the models is based upon the geological characterization of the site at scales relevant to the intended purpose of, or process(es) described by, the specific model. Most of the models in the UZ PMR are based on continuum approximations and employ the dual-permeability approach with van Genuchten equations to describe characteristic curves of both the fracture and matrix continua. The models are supported by site data collected since the early 1980's and the results of field testing in boreholes and underground drifts, which allow for model calibration against field observations, and validation using independent data sets and/or field tests. Uncertainties associated with the models range from uncertainties in individual parameters and processes, to uncertainties in the conceptual and numerical models employed. Some of these uncertainties are due to the fact that the UZ at Yucca Mountain is very heterogeneous. Uncertainty is included in the models for use in TSPA.

The major hydrogeologic units identified at Yucca Mountain are, in order from the land surface to the water table, the Tiva Canyon welded unit (TCw), the Paintbrush nonwelded unit (PTn), the Topopah Spring welded unit (TSw), the Calico Hills nonwelded unit (CHn), and the Crater Flat undifferentiated unit (CFu).

Current climate is expected to persist for approximately the next 600 years, followed by a warmer and wetter monsoon climate for another 1,400 years, and then a cooler, still wetter glacial-transition climate for the remainder of the 10,000-year compliance period. The current best estimate of average net-infiltration of 4.6 mm/yr is expected to increase to an average of 12.2 and 17.8 mm/yr for the monsoon climate and glacial-transition climate, respectively. Percolating water derived from precipitation flows primarily in fractures in the welded units (e.g., TCw and TSw), and in the rock matrix in the nonwelded units (e.g., PTn and CHn (vitric)). Although infiltration is highly episodic, with significant amounts expected to infiltrate for only a few days every 3 to 5 years, the PTn is expected to dampen these pulses, so that water flow below the PTn is assumed to be steady.

The potential repository will reside in three geological units within the TSw. About ten percent of the potential repository volume is located in the middle nonlithophysal unit, 78% in the lower

lithophysal unit and 12% in the lower nonlithophysal unit. More than 80% of water flow at the potential repository horizon is through fractures, while the remainder flows through the low permeability ( $10^{-16}$  to  $10^{-18}$  m<sup>2</sup>) rock matrix. In general, as the infiltration/percolation flux increases, the fraction of the total water flow in the fractures also increases. Bomb-pulse <sup>36</sup>Cl data have verified the existence of fast flow from the land surface to the potential repository horizon; most of the fast flow is associated with known faults. The fracture network permeability in the upper nonlithophysal unit is high but scale-dependent, with large-scale (100 m scale) permeability on the order of  $5 \times 10^{-11}$  m<sup>2</sup>, and smaller-scale (1 m scale) permeability ranging from  $10^{-14}$  to  $10^{-11}$  m<sup>2</sup>. Preliminary field tests show that the average permeability of the lower lithophysal unit may be an order of magnitude higher than that of the upper nonlithophysal unit. Geochemical data such as total chloride (Cl), nonbomb-pulse <sup>36</sup>Cl and calcite fillings in fractures are used to build confidence in the conceptual and numerical models of flow and transport processes occurring in the mountain, and to constrain the predictions of local and global percolation flux.

As a result of the varied geology, critical flow and transport processes differ between the northern and southern parts of the potential repository. Below the horizon of the potential repository, perched water bodies have been found primarily in the northern part of the potential repository area, where low permeability zeolitic rock units are abundant. The presence of the perched water bodies creates the potential for the lateral flow of water to nearby high-permeability vertical features, such as faults. The three-dimensional (3-D) simulations of flow and radionuclide transport in the northern part indicate that flow down the faults increases with depth below the repository, resulting in over 40% of the groundwater recharge occurring through faults. The potential lateral flow and flow through faults have important implications for radionuclide transport, by allowing rapid advective transport from the potential repository to the water table and bypassing of the rock matrix where matrix diffusion and sorption could promote retardation. Larger-size colloids (e.g., plutonium (Pu) colloids) that cannot diffuse into the matrix are particularly susceptible to rapid transport. Beneath the southern part of the potential repository, vitric rock units are present; the vitric rocks potentially provide efficient sorption of some radionuclides such as neptunium (<sup>237</sup>Np). Technetium (<sup>99</sup>Tc) and iodine (<sup>129</sup>I) are non-sorbing and potentially may provide the highest dose rates for the first 10,000 years of the potential repository's life. Daughter products of plutonium (<sup>239</sup>Pu) such as uranium (<sup>235</sup>U) become important after 10,000 years, and therefore must be considered in the abstractions and models for Total System Performance Assessment (TSPA).

The rate of water seepage into drifts is expected to be considerably less than the prevailing percolation flux and may be zero for areas where the percolation flux is lower than the seepage threshold for that location. This is because the drifts act as capillary barriers which drive most of the flowing water around the drifts. The seepage threshold, defined as the percolation flux below which no seepage occurs (for a given location within a hydrogeological unit), depends upon various hydrological parameters, especially fracture permeability and the fracture van Genuchten "alpha" value. The average seepage threshold of the upper nonlithophysal unit is estimated to be 200 mm/yr; no corresponding values have been estimated for the lower lithophysal and lower nonlithophysal units. Based on limited hydrological data and understanding of seepage processes, it is expected that the seepage behavior of these units is similar to that of the upper nonlithophysal unit. Changes in the drift shape due to rock fall may increase seepage; however, estimates based on the current rock fall model show negligible effects on seepage.

As the radioactive waste emits heat, coupled thermal-hydrological-chemical (THC) processes in the UZ rock mass may be important for time periods of up to about 10,000 years. The energy emitted will heat up the entire UZ extending 600 m from the potential repository footprint, with estimated temperature increases of 30 to 35°C at the water table, and up to 5°C at the ground surface. With the assumed design options (Enhanced Design Alternatives II and 50-year ventilation, currently under revision), boiling will occur around the drifts; the region experiencing the boiling temperature (~97°C) will extend out to a maximum of 50 meters into the rock. Temperatures in the mid-pillar regions will increase to 80 to 85°C, but sufficient drainage of condensate is predicted because of the relatively high fracture permeabilities of the potential repository hydrogeological units. As a result, the percolation flux during the thermal period will not greatly exceed the ambient percolation flux for most locations within the potential repository.

The drift-scale models of THC coupled processes predict the chemistry of water and gases entering and occurring around the drifts, and the changes in hydrological properties expected from precipitation/dissolution processes. The results from the models indicate that the water entering the drifts will have relatively neutral pH values, ranging from 7 to 9, and total chloride concentrations that increase to a maximum of about four times the concentrations in the ambient pore water. The precipitation/dissolution of various chemical species and/or minerals was found to have negligible effects on fracture and matrix hydrological properties.

The UZ PMR process models, specifically the Flow Model, the Seepage Model, the Drift-Scale THC Model and the Transport Model, are abstracted for use in TSPA. The degree of abstraction of these models varies from direct use of the process model in TSPA to using the model to justify neglecting certain processes. In the development of the process models, the uncertainties in parameters, processes, and conceptual models are identified and qualified where possible; TSPA then evaluates the importance of these uncertainties on the performance of the potential repository.

In addition to the treatment of the various technical issues on UZ flow and transport, the UZ PMR summarizes concerns and comments by various overseeing bodies such as the Nuclear Regulatory Commission (NRC), the Nuclear Waste Technical Review Board (NWTRB), various peer review groups convened by the Yucca Mountain Site Characterization Project (YMP), and from various internal YMP workshops discussed in Section 2.5. The issues raised by the NRC are of particular interest. In support of the Site Recommendation (SR), the NRC will review current information about the Yucca Mountain site in the UZ PMR, as part of their statutory role in the high-level waste management program. The NRC issues are discussed in detail in Chapter 4 of the UZ PMR.